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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : E21B 43/112, 43/116	A1	(11) International Publication Number: WO 95/09967 (43) International Publication Date: 13 April 1995 (13.04.95)

(21) International Application Number: PCT/US93/09688

(22) International Filing Date: 7 October 1993 (07.10.93)

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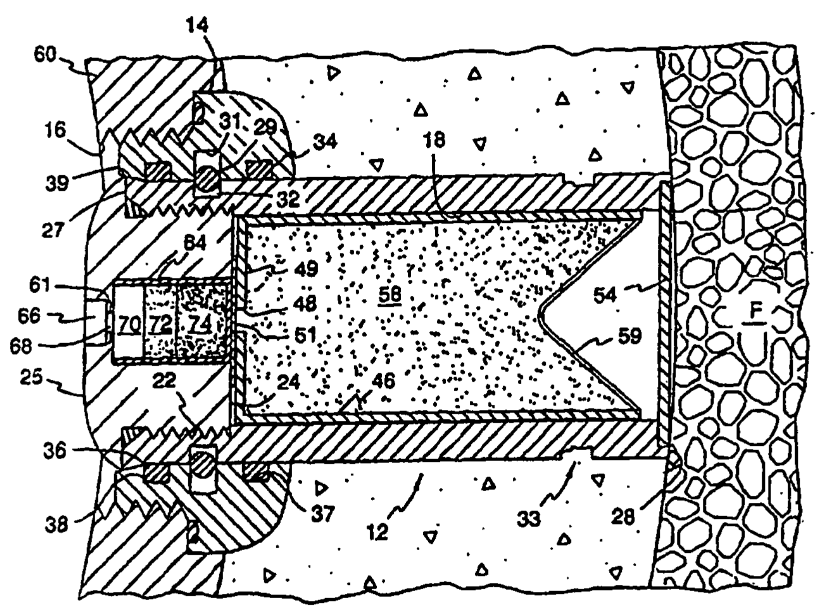
(81) Designated States: GB, NO, US, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: DOWNHOLE ACTIVATED PROCESS AND APPARATUS FOR COMPLETING A WELLBORE



(57) Abstract

A wellbore completion system uses a casing conveyed downhole activated device (50) for establishing a fluid communication flow path between the interior of a casing pipe string (60) and an earth formation (F) traversed by the borehole (W). Flow path devices (50) are mounted in the wall of the casing pipe string (60) and are selectively opened when the casing pressure is less than the formation pressure. The flow path devices (50) may include explosive charges (58, 72, 74) which are arranged in the casing wall. The explosive charges (58, 72, 74) may be detonated by a pressure wave or pulse.

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DOWNHOLE ACTIVATED PROCESS AND APPARATUS FOR COMPLETING A WELLBORE

Field of the Invention

This invention relates to completing a well traversing earth formation in a borehole and more particularly to completing the well by means of flow path devices positioned on a casing string and also by completing the wellbore in an underbalanced pressure condition by means of explosive devices located on the casing string.

Background of the Invention

In the process of establishing an oil or gas well, the well is typically provided with an arrangement for selectively excluding fluid communication with certain zones in the formation to avoid communication with undesirable fluids. A typical method of controlling the zones with which the well is in fluid communication is by running well casing down into the well and then sealing the annulus between the exterior of the casing and the walls of the wellbore with cement. Thereafter, the well casing and cement may be perforated at preselected locations by a perforating device or the like to establish a plurality of fluid flow paths between the pipe and the product bearing zones in the formation. Unfortunately, the process of perforating through the casing and then through the layer of cement dissipates a substantial portion of the energy from the perforating device and the formation receives only a minor portion of the perforating energy.

Additionally, when completing horizontal borehole sections in a well, whether cased or in open holes, it is often a problem getting perforating apparatus into the horizontal section because the gravity factor may not be sufficient to assist in running the equipment and friction between the equipment and borehole walls or pipe further hinders such operations. For this same reason it is difficult in many cases to run casing into such a well, and when casing is installed, the typical bow spring centralizers are ineffective and it is difficult to center the casing in the borehole in order to cement the casing.

Accordingly, it is an object of the present invention to provide a method and apparatus for opening a flow path between the casing string and the formation in a wellbore which overcomes or avoids the above noted limitations and disadvantages of the prior art.

It is a further object of the present invention to provide a method and apparatus for perforating a wellbore wherein a casing string is centered in the wellbore to provide for effective cementing of the casing even when installed in a horizontal borehole, and also where perforating charges are directed into the formation without penetrating a casing pipe when the casing pipe is in an underbalanced pressure condition.

It is yet another object of the present invention to provide a method and apparatus for establishing a fluid communication path between the interior of casing pipe set in a borehole and an earth formation by selectively opening a plurality of flow path devices mounted in the casing wall when the casing pipe bore is at a pressure below the pressure of the earth formation.

Summary of the Invention

The above and other objects and advantages of the

present invention have been achieved in the embodiments illustrated herein by the provision of an apparatus and method for establishing a fluid communication path between the interior of casing pipe set in a borehole and an earth formation by selectively opening a plurality of flow path devices mounted in the casing wall when the casing pipe bore is at a pressure below the pressure of the earth formation. These flow path devices may include explosive charges which are arranged in the casing wall and additionally wherein the charges may be arranged to be detonated by a pressure or shock wave.

Additionally, the charges are placed in extendable pistons mounted in a casing string and a pressure wave producing device is run into the casing string in a separate operation. The casing may also then be cemented before the charges are detonated. By placing the charges in pistons extendable from the casing string, the charges are directed into the formation without passing through the casing and/or cement.

In one embodiment, the system comprises a piston for being mounted in an opening in the peripheral wall of the pipe and for extending generally radially outwardly from the pipe to contact the wall of the wellbore wherein the piston includes an explosive device therein. A deploying device deploys the piston from a retracted position which is generally within the maximum exterior profile of the pipe to an extended position wherein the piston extends generally radially from the opening to contact the wall of the wellbore. A detonation device is then positioned in the wellbore for detonating the explosive device in the piston while the piston is in its deployed position against the wall of the formation so as to perforate the formation by an explosive proximate to the formation. The piston when extended serves to center the

pipe in the borehole and is substantially clear of the inner bore of the pipe to render the bore of the pipe full open.

In addition, the system may include a tubing string installed within the casing pipe wherein the bore of the casing pipe is placed in an underbalanced pressure condition prior to opening the flow path devices. The tubing string may be provided with a packer or the like to close off the annular space between the tubing string and the casing.

Brief Description of the Drawings

Figure 1 is a cross-sectional view of a wellbore traversing earth formations with a casing string arranged therein and spaced from the walls of the wellbore by a plurality of downhole activated pistons which are shown being activated to an extended position and which embody features of the present invention.

Figure 2 is an enlarged cross-sectional end view of the casing taking along lines 2-2 in Figure 1, wherein the centralizers are shown extended to center the casing string in the wellbore.

Figure 3 is a cross-sectional end view similar to Figure 2 prior to the casing being centralized and with the downhole activated centralizers in the retracted position.

Figure 4 is an enlarged cross-sectional view of a centralizer piston having a detonation device and shaped charge positioned therein, with the piston shown in a retracted or running-in position relative to the casing wall.

Figure 5 is an enlarged cross-sectional view of the centralizer piston of Figure 4 in an extended position wherein the outer end of the piston is in contact with an earth formation.

Figure 6 is a cross-sectional view of a wellbore showing a casing centralized in a borehole by pistons in an extended position and further showing a pressure wave generating device positioned in the casing by means of a tubing string.

Detailed Description of the Preferred Embodiments

Referring first to Figure 1 of the drawings, a wellbore W is shown having been drilled into the earth formations such as for the exploration and production of oil and gas. The illustrated wellbore W includes a generally vertical section A, a radial section B leading to a horizontal section C. The wellbore has penetrated several formations, one of which may be a hydrocarbon-bearing zone F. Moreover, the wellbore W was drilled to include a horizontal section C which has a long span of contact with the formation F of interest, which may be a hydrocarbon-bearing zone. With a long span of contact within a pay zone, it is likely that more of the hydrocarbon present will be produced. Unfortunately, there are adjacent zones which have fluids such as brine that may get into the production stream and thereafter have to be separated from the hydrocarbon fluids and disposed of at additional costs. Accordingly, fluid communication with such adjacent zones is preferably avoided.

To avoid such communication with nonproduct-bearing zones, wellbores are typically cased and cemented and thereafter perforated along the pay zones. However, in the highly deviated portions of a wellbore such as the radial section B and the horizontal section C of the wellbore, the casing tends to lay against the bottom wall of the wellbore, thereby preventing cement from encircling the casing and leaving a void for wellbore fluids such as brine to travel along the wellbore and enter the casing far

from the formation from which it is produced. In the illustrated wellbore W, a casing string or liner 60 has been run therein which is spaced from the walls of the wellbore by a plurality of downhole activated pistons generally indicated by the number 50, which serve to centralize the casing. The downhole activated pistons or centralizers 50 are retracted into the casing 60 while it is being run into the wellbore as is illustrated by the centralizers 50 in Figure 1 which are ahead of an activator or pusher 82. Once the casing 60 is suitably positioned, the centralizers 50 are deployed to project outwardly from the casing as illustrated behind the activator or in Figure 1. The centralizers 50 move the casing from the walls of the wellbore if the casing 60 is laying against the wall or if the casing is within a predetermined proximity to the wall of the wellbore W. This movement away from the walls of the wellbore will thereby establish an annular free space around the casing 60. The centralizers 50 maintain the spacing between the casing 60 and the walls of the wellbore W while cement is injected into the annular free space to set the casing 60. The pistons, however, are latched in an extended position and will thereby maintain the casing 60 centered even if the casing is not cemented.

The centralizers 50 are better illustrated in Figures 2 and 3 wherein they are shown in the extended and retracted positions, respectively. Referring specifically to Figure 2, seven centralizers 50 are illustrated for supporting the casing 60 away from the walls of the wellbore W although only four are actually shown contacting the walls of the wellbore W. It should be recognized and understood that the centralizers work in a cooperative effort to centralize the casing 60 in the wellbore W. The placement of th centralizers 50 in the casing 60 may be

arranged in any of a great variety of arrangements. Applicants' related U.S. Patent No. 5,228,518 which is incorporated herein by reference describes these arrangements in greater detail.

Referring again to Figures 2 and 3, the 7 illustrated centralizers 50 are evenly spaced around the casing 60. As the casing is centralized, an annular space 70 is created around the casing within the wellbore. The casing 60 is run into the wellbore with the centralizers 50 retracted as illustrated in Figure 3 which allows substantial clearance around the casing 60 and permit the casing 60 to follow the bends and turns of the wellbore W. Such bends and turns particularly arise in a highly deviated or horizontal hole. With the centralizers 50 retracted, the casing 60 may be rotated and reciprocated to work it into a suitable position within the wellbore. Moreover, the slim dimension of the casing 60 with the centralizers 50 retracted (Figure 3) may allow it to be run into wellbores that have a narrow dimension or that have narrow fittings or other restrictions.

In Figures 2 and 3 and in subsequent figures as will be explained below, the centralizers 50 may present small bulbous portions 80 on the outside of the casing 60. It is preferable not to have any dimension projecting out from the casing to minimize drag and potential hangups while moving the string. However, as will be discussed below, the bulbous portions 80 are utilized in some embodiments especially in smaller diameter casings such is often used in horizontal holes when they are cased. It should also be recognized that the bulbous portions 80 are rounded to slide better along the walls of the wellbore and that the casing string 60 will include collar sections 90 that will extend out radially farther than the bulbous portion (see Figure 3). Thus, the collar sections 90

present the maximum outer profile of the casing string even when the bulbous portions are present. The outward projection of the retracted centralizers 50 being within the maximum outer profile of the casing string 60 is believed to minimize any problems of running the casing.

Referring again to Figure 1, a deploying device or pusher 82 which moves from the top of the casing to its bottom end is shown positioned within the horizontal curved section B of the casing string. The deploying device 82 is sized to push the pistons 50 from a retracted to an extended position. It is noted that the centralizers or pistons 50 behind or to the left of the pusher 82 are in an extended position having been engaged by the tapered nose portion 85 of the pusher. The tapered portion 85 engages the inner ends of the pistons and pushes them outwardly as the piston travels until the body portion 83 has passed the piston whereupon the piston will be fully extended and locked into an extended position as will be hereinafter described. The centralizers in front of the pusher 82 are still in a retracted position and consequently the horizontal portion C of the casing in front of the pusher is shown lying on the bottom side of the borehole. The upper vertical section A and radial section B are shown centered in that the pistons 50 have been deployed to an extended position. The activator device shown in Figure 1 is a pumpable activator or deploying device having a tail pipe 81 which extends rearwardly from the main body portion 83 and seals the rear end of the device to the inside of the casing so that the device may be pushed down through the casing 60 by the application of hydraulic pressure. In addition, the activator may be run into the casing string on the end of a pipe string such as a drill pipe or coiled tubing wherein force is applied to the pipe string and thus to an activation device to engage and push out or extend

the pistons 50.

The centralizers or pistons may take many forms and shapes as is also described in Patent No. 5,246,861. In the present application, the piston or centralizer 50 is shown in Figures 4 and 5 as including an explosive charge for perforating formations in the borehole. Referring first to Figure 4, the centralizer 50 has a cylindrical or substantially cylindrical barrel portion or piston 12 which is slidably received in a bore in button 14. The button 14 is threadedly received within a tapped hole 16 which extends transversely through the wall of casing 60. A bulbous or rounded outer portion 80 extends outwardly slightly beyond the outside wall of the casing 60 but only to provide an adequate seat for the button 14 in thin wall smaller diameter casing and is constructed so that the outer extension of the bulbous portion 80 does not exceed the maximum profile of the pipe string which would normally be represented by the outside diameter of collars 90 in the casing string. The button 14 has a shoulder 17 formed at the base of the bulbous outer portion 80 that provides a surface for seating within a mating recessed surface at the outer end of the threaded hole 16 in the casing wall. The shoulder 17 forms a vertical surface on the button which fits against the mating vertical surface at the outer end of hole 16. An O-ring 18 is arranged within a groove on the shoulder 17 to provide a seal between the shoulder 17 and a vertical face at the end of hole 16. The button 14 is arranged so that its inner end does not extend into the interior of the casing 60. The piston 12 is arranged for axial movement through the button 14 from a retracted position (Figures 3 and 4) to an extended position (Figures 2 and 5). The piston 12 and the button 14 are mounted into casing 60 so that their axis are collinear and directed radially outwardly with respect to the axis of the casing

60. The piston 12 includes a plug 19 secured in an interior bore or passageway 18 in the piston by screw threads 22. An annular sealing ring 21 is positioned between the plug 19 and the inner end of piston 12. The piston 12 shown in Figures 4 and 5 also serves as a housing for a perforating device. The plug 19 is called an initiator plug in that it carries a device for initiating detonation of a shaped charge in the piston. The plug 19 does not fill the entire passageway 18 but is rather approximately the thickness of the casing 60. The plug 19 further includes a rounded inner end face 25 and a flat distal end face 24. The rounded surface 25 on the inner end of plug 19 is provided for facilitating the use of a deploying device to push the centralizer 50 into an extended position.

The distal end 28 of the piston 12 may be chamfered or tapered inwardly to ease the installation of the piston 12 into the button 14. The piston 12 is mounted in a central bore in the button 14 which is preferably coaxial to the opening 16 in the casing 60 and is held in place by a snap ring 29. The snap ring 29 is located in a snap ring groove 31 milled in the wall of the interior bore of the button 14.

Piston 12 includes two radial piston grooves 32 and 33 formed in the exterior cylindrical surface of the piston 12. The first of the two piston grooves is a circumferential securing or locking groove 32 which is positioned adjacent the inner end 27 of piston 12 to be engaged by the snap ring 29 when the piston is fully extended. The second of the two grooves is a circumferential retaining groove 33 positioned adjacent the distal end 28 of the cylinder 12 to be engaged by the snap ring 29 when the piston is in the retracted or running position as shown in Figure 4. As the piston 12 is

illustrated in Figure 5 in the extended position, the snap ring 29 is engaged in the radial locking groove 32.

The snap ring 29 is made of a strong resilient material arranged to expand into the snap ring groove 31 when forced outwardly and to collapse when unsupported into the grooves 32 and 33 when aligned therewith. A particular arrangement of snap ring and grooves is shown in greater detail in Applicants' copending U.S. Application Serial No. 08/051,032, incorporated herein by reference.

Once the casing 60 is positioned in the wellbore for permanent installation, the pistons are deployed to the extended position. The deploying method provides a deploying force on the inner end of each piston to overcome the resistance of the snap ring in the retaining groove 33 and cause the snap ring 29 to ride up and out of the retaining groove 33 whereupon the snap ring 29 is pushed up into the snap ring groove 31 within the button 14. This allows the piston to move out into the annular space of the wellbore. Once the piston encounters the wellbore wall, it will then lift the casing off of the wellbore to centralize the casing until such time as the snap ring 29 aligns with and expands into the locking groove 32. The pistons should be of such a length that the pistons can be fully deployed to the locking groove 32 while giving the maximum amount of centralization. Once the pistons are fully deployed, the inner surface 25 on the plug 19 will be substantially clear of the casing bore for all practical purposes, and the casing bore should be substantially full opened.

The button 14 further includes a sealing arrangement to provide a pressure tight seal between the piston 12 and the button 14. In particular, the button 14 includes two O-rings, 34 and 36, which are positioned on either side of the snap ring 29 in O-ring grooves 37 and 38, respectively. The O-rings 34 and 36 seal against the

exterior of piston 12 to prevent fluids from passing from one side of the casing wall to the other through the bore of the button 14. The O-rings 34 and 36 must slide along the exterior of the piston 12 passing the piston grooves 32 and 33 while maintaining the pressure tight seal.

The piston 12 further includes an outwardly tapered enlarged diameter peripheral edge 39 on its inner end 27, which edge 39 is larger than the bore in button 14 that receives the piston 12. Thus the edge 39 serves as a stop against the button 14 to limit the outward movement of the piston 12. The inside face of button 14 includes a chamfered edge 41 for engaging the outwardly tapered peripheral edge 39 on the piston when the inner end 27 of the piston is approximately flush with the inner end face of the button 14. Therefore, while the extended piston 12 is recessed into the button 14 and clear of the interior bore of the casing 60, the inwardly facing rounded surface 25 of the initiator plug extends slightly into the bore of the casing for purposes to be described so that it is substantially clear of the bore to render the casing bore fully open to permit passage of the deploying device 82 or other similar device such as packers or the like that would be passed through the bore of a casing string.

The term full open bore within the context of oil field terminology, encompasses a situation such as the present wherein for all practical purposes equipment can be moved through the bore of a pipe unrestrictedly.

Still referring to Figure 4, the inner bore 18 of the piston 12 is shown having a shaped charge insert installed therein. The shaped charge insert includes a cup-shaped canister or carrier 46 which is sized to be press fit into the bore 18 of the piston 12. A locking compound is used to hold the canister 46 in the bore cavity of the piston. The carrier 46 is nested against a shoulder

47 in the piston bore 18, the shoulder 47 being the end of the threads 22 which are cut in the bore 18 of the piston at its inner end to receive plug 19. An ignition hole 48 is formed in the inner wall 49 of the cup-shaped carrier 46. A thin metal foil 51 is placed over the outer surface of hole 48 facing the plug 19. At the distal end of the piston 12, an outer end cap 54 is fitted within a recessed shoulder 55 and is held in place by its press fit and a locking compound. A shaped charge 58 is positioned in the canister 46 with a conical depression 59 in the distal end of the face of the shaped charge facing outwardly.

The opposite inner end of the piston 12 has the plug 19 enclosing the inner end. The plug 19 has a cylindrical recess 62 which is formed from the inner side of the plug 19 for receiving a detonator cup 64. The cup 64 is held in place within the recess 62 by means of a thread locking compound or the like. On the rounded outer surface 25 of the plug 19 and central to the plug 19, a recess 66 is formed in the outer wall surface 25 opposite the recess 62 on the interior of the plug 19. The recess 66 may be for example 1/8 inch in diameter and approximately .040 inches deep to leave an integral rupture disc portion 68 formed between the recesses 62 and 66. The rupture disc may be on the order of .0275 inches thick. The cup 64 which is assembled within the recess 62 has provided within its interior bore a detonating system which is comprised of an air space 70, a plug of lead azide 72, and a plug of RDX explosive 74.

In Figure 5 of the drawings, the centralizing piston 12 is shown having been moved to an extended and locked position wherein the distal end 28 of the piston is in contact with the bore hole wall. A deploying device 82 such as is shown in Figure 1 has been moved through the interior bore of the casing string to contact the outer

surface 25 of plug 19 on the inner end of the piston. Once the piston is extended and locked in its predetermined fixed position as shown in Figure 5, the perforating apparatus is now in a position to permit perforation of the formation which the wellbore traverses. It is noted, that alternatively the pistons 12 may be extended by the application of hydraulic pressure to the interior of the casing pipe string which provides a force that impinges on the inner end of the piston to move the pistons outwardly.

It is to be noted that one particular advantage of the apparatus described herein is that the centralizing piston and a button 14 which guides the piston, when provided, may be assembled within the casing string at some time just before the casing is run into the wellbore W. Accordingly, the handling of the casing pipe up to the point that it is being installed in the wellbore is not subjected to the danger which would be caused by having the explosive devices installed during shipping and handling of the casing prior to its installation. It is also to be noted that there is no device present within the system thus far described to initiate the explosive device within the piston so that such handling in the configuration described above is considered safe and will not unnecessarily endanger the personnel who are installing the devices in the casing or installing the casing within the wellbore.

Referring now to Figure 6 of the drawings, the casing 60 is shown having been run into a well. The centralizers are shown having been extended by means of a pumpable activator device 82 such as shown in Figure 1 or by the application of hydraulic pressure to the casing string at the surface. Hydraulic activation is accomplished by closing a valve at the base of the casing string and applying the necessary activation or deploying

force required to move the pistons from the retracted position to the extended position. Accordingly, pumps or other pressure generating mechanism would provide the necessary deploying force for the pistons.

Once the casing has been centralized within the wellbore, an annulus of cement can be injected and set around the entire outer periphery of the casing, over some appropriate interval of casing, to seal the casing from the formation. As suggested by the present invention, the casing string with the centralizer system as described is arranged so that in those portions of the wellbore where it is desired to have a centralizing only function for the centralizers, the centralizers are not configured so as to provide a perforating function. However, within a zone opposite formation F as shown in Figure 6, where it is desirable to open the casing to permit the recovery of fluids from the formation into the casing string and to perforate the formation, the centralizers are of the embodiment shown in Figures 4 and 5 which include a shaped charge device or the like for perforating the formation to be produced.

In the initial installation of the casing within the wellbore, it is important to note that when the centralizers are not extended the casing can be rotated and reciprocated to work past tight spots or other interferences in the hole. These retracted centralizers 50 also do not interfere with the fluid path through the casing string so that fluids may be circulated through the casing to clear cuttings from the end of the casing string. Also the casing interior can be provided with fluids that are less dense than the wellbore fluids, in the annular space, causing the casing string to float. Clearly, the centralizers 50 of the present invention permit a variety of methods for installing the casing into its desired

location in the wellbore.

Once the casing 60 is in a suitable position, the centralizers are deployed to centralize the casing. As discussed above, there are several methods of deploying the centralizers. Once the pistons are all deployed and the snap rings have secured them in the extended fixed position projecting outwardly toward the wall of the wellbore, the cement may be injected by well known techniques into the annulus formed by the centralizing of the casing within the borehole.

The cement around casing 60 may be allowed to set while the production string is assembled and installed into the casing. It is important to note that at this point in the process of establishing the well, the casing and wellbore are sealed from the formation. Accordingly, there is as yet no problem with controlling the pressure of the formation or with loss of pressure control fluids into the formation. In a conventional completion process, the perforation string is assembled to create perforations in the casing adjacent to the hydrocarbon bearing zone. Accordingly, high density fluids are provided in the wellbore to maintain a sufficient pressure head against the affect of formation pressure to avoid a blowout situation. While the production string is assembled and run into the well some of the wellbore fluids, in an overbalance condition, may be forced into the formation. Accordingly, the production string must be installed quickly to begin producing the well once the well has been perforated. However, with the present invention, such problems are avoided. Once the casing is set in place, the production string may be assembled and installed in the casing before perforation of the formation is performed. Once the production string is in place in the well, adequate surface controls are in place to prevent a blowout, so that the

casing and production string can be in an underbalanced condition. The packer 86 as shown in Figure 6 seals off the casing string annulus between the production tubing 89 and the casing 60. This packer is set above the pistons 50 to be opened as flow paths. Thus, production may begin when communication is established with the formation, such as by perforation in any under balanced condition. Accordingly, the well is brought on-line in a more controlled manner. It is well documented that perforating underbalanced gives higher production rates in many wells. Underbalanced perforating is a term which describes the concept of having a lower pressure in the well than in the adjacent formation. When a well is perforated underbalanced the pressure in the formation is allowed to enter the wellbore. When a well is perforated overbalanced the pressure in the wellbore is allowed to enter the formation. The flow of fluids into the formation in overbalanced perforating can damage the formation reducing permeability and later the flow into the wellbore. Underbalanced perforating will not cause this formation damage. It also appears that damage caused by the perforating itself is reduced if a well is perforated underbalanced. Wells can be perforated underbalanced with wireline guns but the well must be overbalanced when the production tubing is run in the well or a major safety problem exists. The casing conveyed perforating described herein allows underbalanced perforating in all types of wells and does not require that the well ever be overbalanced because the production tubing can be present in the well during the perforating and can be placed immediately on production without ever having to kill the well.

It is noted that the centralizing pistons 50 may be made so that they can be opened to serve as a flow path by means of chemical activation as opposed to explosive

activation. Such an arrangement is described in U.S. Patent 5,228,518. This may be accomplished for example, by having the closures at each end of the piston bore made of a material that is dissolvable in a fluid. If plug 19 and end cap 54 are made of magnesium or aluminum an acid solution can be used to rapidly dissolve these materials.

Figure 6 shows an apparatus and system for initiating the detonators within the detonator cup 64 (Figure 5) in the pistons, in order to fire the shaped charges and penetrate the formation. Firing the detonators will also open the piston to fluid flow between the formation and casing string. A small diameter pipe string such as production tubing 76 or coiled tubing is run into the interior of the casing string after the centralizers 50 are extended but before the detonators are fired. The casing string may be in the form of a longstring which extends from the bottom of the wellbore to the surface or in the form of a liner where the casing is required over some specific zone in the wellbore which does not extend to the surface. Such a liner is normally set using drill pipe. However, the casing may or may not be cemented in place. A primer cord 84 may be pre-installed in the lower end of the tubing string 76 and run into the well with the tubing string. Alternatively, the tubing string may be located in the casing string and then the primer cord is run into the tubing string. In the latter case, in order to set the primer cord 84 in place, the bottom of the tubing string can be provided with a latching mechanism 93. After the tubing 76 is run into the casing string, a sinker bar with primer cord trailing behind, can be lowered into the tubing string and latched inside of the tubing. Alternatively, a device can be pumped to the latch 93 with a primer cord trailing. A perforating head 89 would be run at the trailing, upper end of the primer cord 84 to provide

a means for initiating the primer cord. Once the tubing is run, a production packer 86 can be set. At this time a sinker bar 91 can be dropped which would strike the perforating head and initiate the primer cord. Alternatively, a wireline could be connected with the primer cord or perforating head in order to initiate the primer cord.

The primer cord is initiated by dropping a similar bar 91 or using an electrical wireline or as another alternative, using a hydraulically actuated perforating head. Once the primer cord is initiated, it results in the development and propagation of a pressure wave within the pipe string 76. This pressure wave is then communicated through the fluid in the pipe 76 and casing 60 to the plug 19 at the inner end of the cylinders 12. If necessary, the pipe string 76 may be centered in the casing by means of conventional centralizers 78. Centering the pipe string 76 in the casing string may be important in view of the importance of propagating a pressure wave to the cylinders 12 on all sides so that the force of this pressure wave is sufficient to rupture the disc 68 in the plug 19. This rupture of disc 68 will sequentially initiate the powders 72 and 74 within the cup 64 positioned in the plug 19. Tests have shown that initiation of the detonator will take place without the provision of an air space 70 in the cup 64 by locating powders adjacent to the ruptured disc 68. The amount of pressure required to rupture the disc is increased when the air space is eliminated; however, detonation does take place. It is believed that the principle behind the detonation is an adiabatic compression within the cup 64 which is sufficient to initiate the powders 72, 74 therein. Therefore, it appears to only be necessary to generate sufficient pressure within the interior of the casing bore to cause

the rupture disc 68 to rupture which will thereby initiate the detonator housed within the cup 64. When a shaped charge is present in the piston 12, initiation of the detonator is communicated through the opening 48 within the carrier 46 to detonate the shaped charge 58. This detonation produces a penetrating force that is directly applied to the formation F so that all the outwardly directed energy of the shaped charge is applied to perforation and fracturing of the formation. Detonation of the shaped charge 58 also removes the plug 19 and end cap 54 to open the piston 12 for fluid flow.

In the configuration shown in Figure 6, the smaller diameter pipe 76 housing the primer cord, may be provided with slots or holes in the outside walls thereof to facilitate transmission of a pressure wave emanating from the primer cord to the perforating cylinders 12. However, experiments have shown that a pressure wave may be propagated through the walls of solid pipe which is sufficient to initiate the detonators within the plug 19 on the cylinders 12. The system shown in Figure 6 with a production packer 86 set in place will permit the completion to take place with an under-balanced fluid in the pipe string, so that upon perforation of the formation F formation, fluids may be readily received into the casing string through the now open cylinder 12 and from there into the production tubing 76 for conveyance to the surface.

In the process of perforating the formation as described in the present invention, it is noted that the word "penetrating" is used to describe the process for opening a communication path into the formation. The reason that penetrating the formation is desirable is that the permeability of porous reservoir rock is usually reduced or plugged near the wellbore due to the leakage of drilling fluids used in the drilling operation into the

first few inches of the formation material surrounding the wellbore. This reduces permeability near the wellbore and is referred to as skin damage. In the present perforating technique, the shaped charges are not designed to make a hole in the casing as in a normal perforating system, but rather to establish communication with the reservoir rock and to penetrate the rock itself with a fracturing and penetrating blast that extends communication beyond the skin damage. Whereas normal shape charges in a perforating system are positioned within the casing string and must therefore progress through the fluids within the casing string, the steel casing string wall, cement if it is in place, and then into the skin damaged portion of the reservoir. In the present system the shape charge is positioned directly against the formation and thus a much greater portion of the energy developed by the shaped charge is applied to the formation rock itself.

It is readily appreciated that various other techniques could be developed for providing the placement of a primer cord into the interior of either a casing pipe string or a production string in order to initiate the pressure wave described herein for detonating the perforation devices. For example, the primer cord could be pumped in behind a pumpable plug or the like to position the primer cord into a horizontal reach of pipe. In a vertical or nearly vertical pipe section, gravity would be sufficient to lower a primer cord weighted on its lower end, into a pipe string. In addition, other methods could be used to develop a pressure wave for initiating the shaped charge. Also, it is readily seen that a variety of detonators might be used to initiate the explosion of the shaped charged within the centralizing cylinder 12. Additionally, while a casing string has been primarily described as the device for carrying the extendible pistons

or flow path devices into the borehole, it is readily appreciated that liners serve the same purpose and therefore any functional substitute for a casing is intended to be covered by this invention. Therefore, while particular embodiments of the present invention have been shown and described, it is apparent that changes and modifications may be made without departing from this invention in its broader aspects and therefore the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

In the Claims:

Claim 1. A method for completing a borehole traversing earth formations, comprising the steps of;

installing detonating devices in the side walls of a casing pipe string, said detonating devices being operable to open a flow path in the wall of the casing pipe string;

setting the casing pipe string in the borehole;

placing the interior bore of said casing pipe string at a pressure below the formation pressure; and

activating said detonating devices to open said casing pipe to said formation.

Claim 2. The method of claim 1 and further including running a production tubing into the casing pipe string before activating said detonating devices.

Claim 3. The method of claim 2 and further including packing off an annular space between the production tubing and the casing pipe above the detonating devices.

Claim 4. The method of claim 2 wherein the step of activating said detonating devices includes placing an activation means in the production tubing, and operating said activation means.

Claim 5. The method of claim 3 wherein said activation means is a primer-cord device.

Claim 6. The method of claim 1 and further including;

running an activating means into the borehole after the casing pipe string is set in the borehole; and

operating the activation means to initiate the detonating device.

Claim 7. The method of claim 1 wherein shaped charges are mounted on said casing pipe, and further including detonating said shaped charges to penetrate the earth formations.

Claim 8. The method of claim 7 wherein said shaped charges are arranged in a piston in the side walls of the casing pipe and further including extending said pistons outwardly from the side of the pipe into contact with the earth formation.

Claim 9. The method of claim 7 wherein said shaped charges are mounted in pistons which are laterally extensible from a retracted position in the side wall of the casing pipe to an extended position in contact with the formation and further including before activating said detonating devices, extending said pistons toward contact with the formation to center the casing pipe in the borehole.

Claim 10. Apparatus for completing a borehole drilled into earth formations wherein it is desirable to establish a fluid communication path between the interior of casing pipe set in the borehole and an earth formation traversed by the borehole, comprising;

a casing pipe string made up of sections of casing pip ;

detonator means for being mounted on said casing pipe prior to said casing pipe being installed in the boreholes, said detonating devices being operable to open a flow path in the wall of the casing pipe;

means for placing said casing pipe string at a pressure below the pressure of the earth formation in which it is to be positioned; and

means for activating said detonating device to open said casing pipe to the formation.

Claim 11. The apparatus of claim 10 and further including means separate from and unattached to said casing pipe string for operating said activation means to open said casing pipe string.

Claim 12. The apparatus of claim 10 wherein said detonator means includes shaped charges and detonator charges arranged in pistons, which pistons are mounted in the side wall of the casing pipe string.

Claim 13. The apparatus of claim 12 and further including means moveable through the interior bore of the casing pipe string for pushing said pistons outwardly through the side wall of the casing pipe toward contact with the earth formation.

Claim 14. The apparatus of claim 11 wherein said means for operating said activation means is a primer cord device for placement in the casing pipe near said detonator means.

Claim 15. The apparatus of claim 14 and further including production tubing in said casing pipe string, wherein said primer cord device is positioned in said

production tubing.

Claim 16. The apparatus of claim 15 and further including packer means for packing off an annular space between the production tubing and casing pipe above the detonating devices.

Claim 17. A method for completing a borehole drilled into earth formations to develop a fluid communication path between the formations and a pipe string in the borehole, comprising the steps of;

installing explosive devices in the wall of a casing pipe;

running the casing pipe into the borehole;

cementing the casing pipe in the borehole;

placing the interior of the casing pipe at a pressure which is less than the formation pressure; and

initiating the explosive devices to open a fluid communication path between the casing pipe and the formation adjacent the casing pipe.

Claim 18. The method of claim 17 wherein said explosive devices are arranged in pistons mounted for movement between retracted and extended positions in the wall of the pipe string, and further including;

extending said pistons toward the formation to center the casing pipe in the borehole before cementing the casing pipe.

Claim 19. The method of claim 17 and further including, after cementing the pipe, running an explosive initiating device into the casing pipe for initiating the explosive devices.

Claim 20. The method of claim 17 and further including running a primer cord device into the casing pipe after cementing the casing pipe for initiating the explosive devices.

Claim 21. A method for completing a borehole drilled into earth formations to develop a fluid communication path between the formations and a pipe string in the borehole, comprising the steps of:

installing flow path devices in portions of a casing pipe string which when activated will provide a flow path from the outside to the inside of the casing pipe string;

installing said casing pipe string in the borehole adjacent formations to be completed with fluid in said casing pipe string and borehole being overbalanced relative to formation fluid pressure;

installing a production tubing in the casing pipe string, with the production tubing having a packer for closing off an annular space between the production tubing string and the casing pipe string above the formations to be completed;

circulating an underbalanced fluid through the production tubing and casing pipe string;

setting the packer to close off said annular space; and

activating said flow path devices in said casing pipe string to open a flow path between formations to be completed and the inside of the casing pipe string below the packer.

Claim 22. The method of Claim 21 and further wherein said flow path devices are extendible pistons mounted in the sidewall of the casing pipe string and further including, prior to installing the production

tubing, passing a device through the interior of the casing pipe to extend the pistons.

Claim 23. The method of Claim 21 and further including running a primer cord into the production tubing and initiating said primer cord to activate said flow path device.

Claim 24. The method of Claim 21 and further including positioning a primer cord in said production tubing prior to its being installed in the casing pipe string; and

initiating said primer cord to activate said flow path device.

Claim 25. Apparatus for completing a borehole drilled into earth formations to develop a fluid communication path between the formations and a pipe string in the borehole, comprising;

a casing pipe string positioned in the borehole adjacent formations to be completed and having an overbalanced fluid column therein providing a hydrostatic head greater than the formation pressure;

a tubing string positioned in the casing string;

selectively operable packer means positioned on the tubing string and positioned above the formations to be completed;

means for closing the bottom of the casing string to outward fluid flow;

means for displacing the overbalanced fluid column from the casing pipe string below the packer;

means for operating said packer means to close off the annulus between the tubing string and the casing pipe string after displacing the overbalanced fluid column;

selectively operable flow path means mounted on said casing; and

means for operating said flow path means.

Claim 26. The apparatus of Claim 25 and further wherein said selectively operable flow path means is comprised of a plurality normally closed passageways mounted in the sidewall of a portion of said casing pipe string.

Claim 27. The apparatus of Claim 25 and further wherein said selectively operable flow path means includes an explosive component which when activated opens said flow path means to fluid communication between the formations to be completed and the interior bore of said casing pipe string.

Claim 28. The apparatus of Claim 25 and further wherein said means for operating said flow path means is comprised of means which is controlled from the earth's surface for activating said explosive component in said flow path means.

Claim 29. The apparatus of Claim 25 wherein said operating means is positioned within said tubing string.

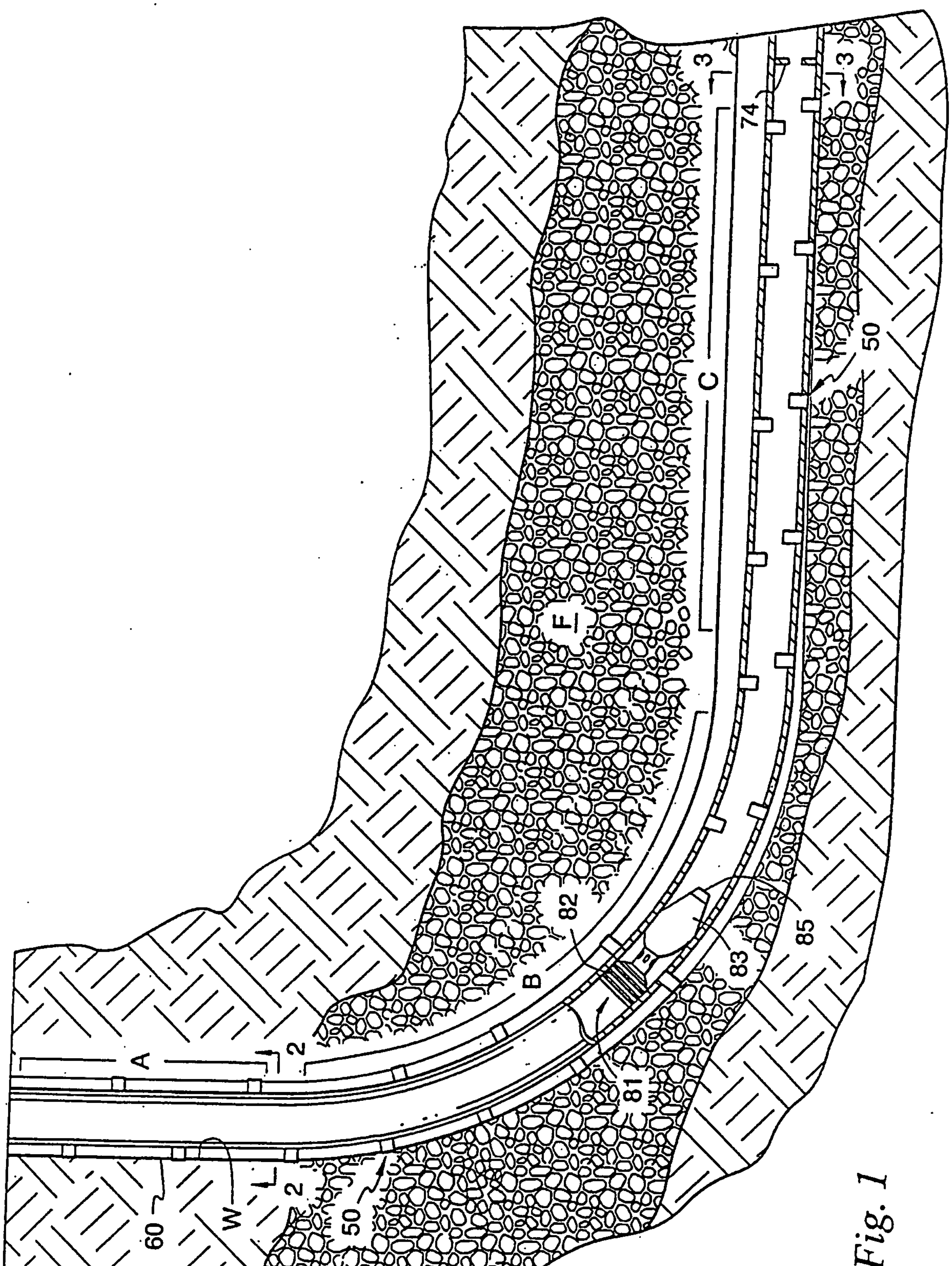

Fig. 1

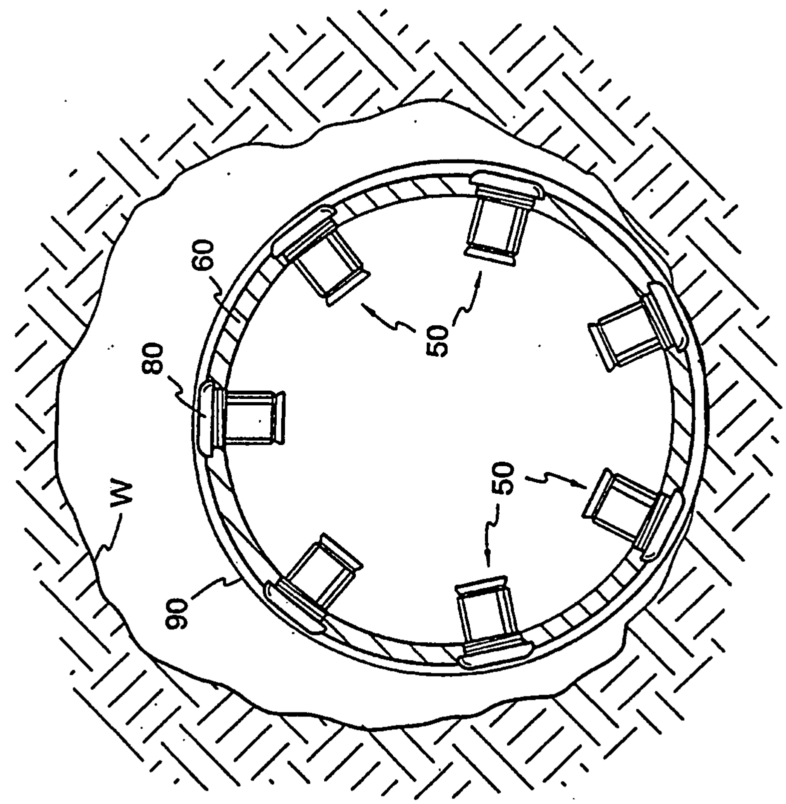

Fig. 3

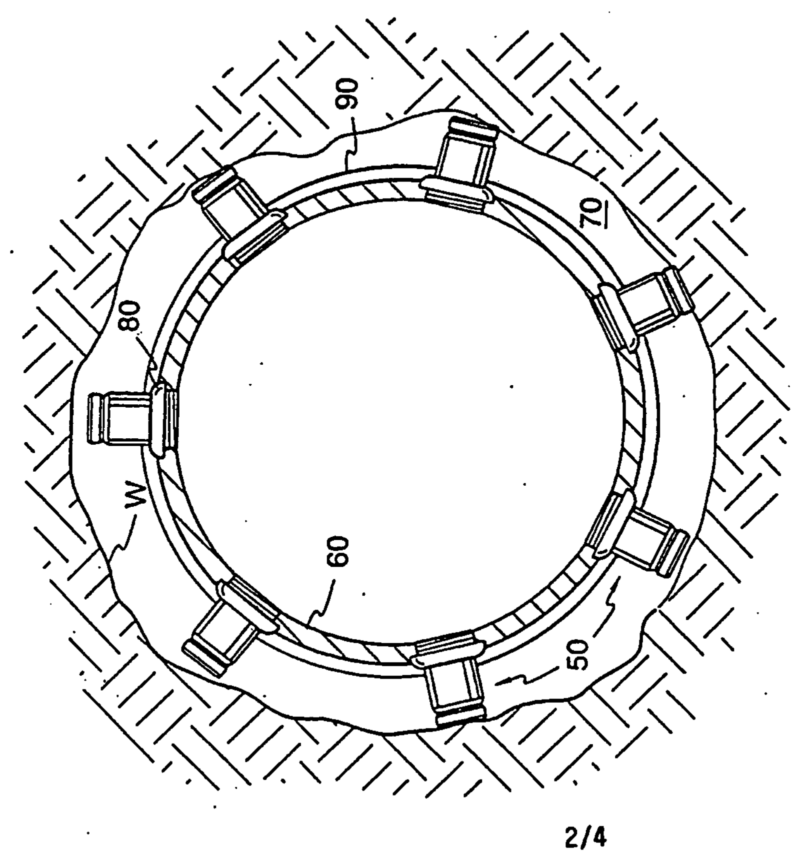

Fig. 2

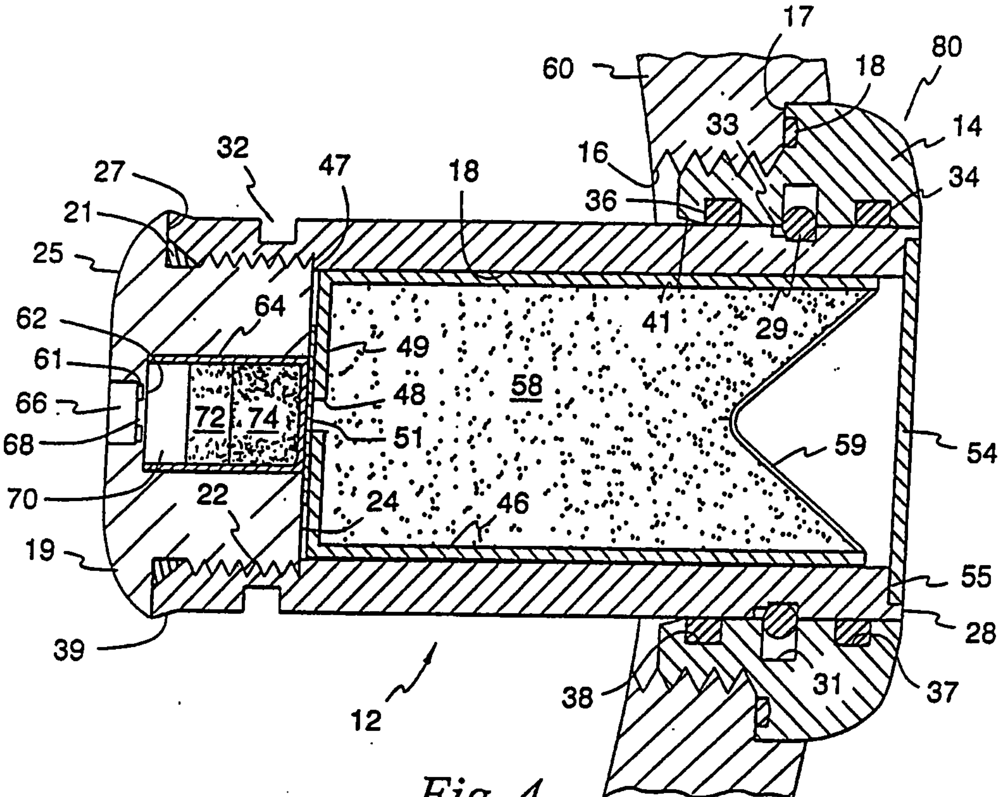

Fig. 4

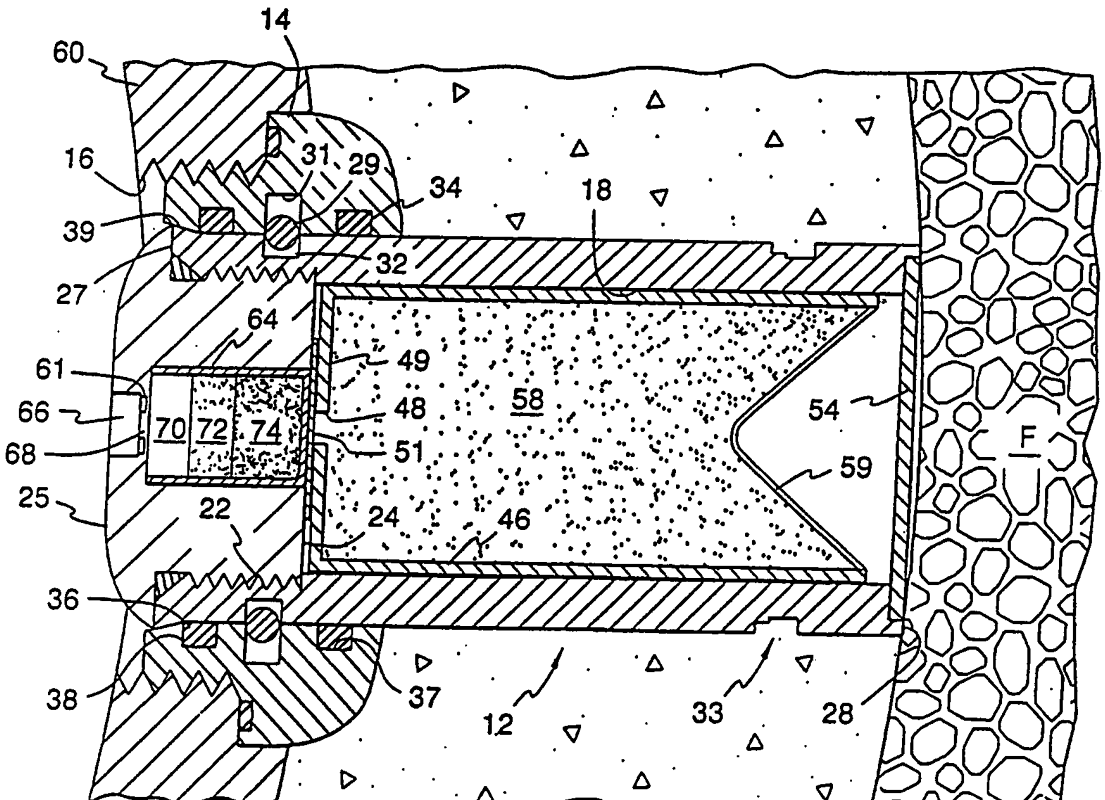

Fig. 5

SUBSTITUTE SHEET

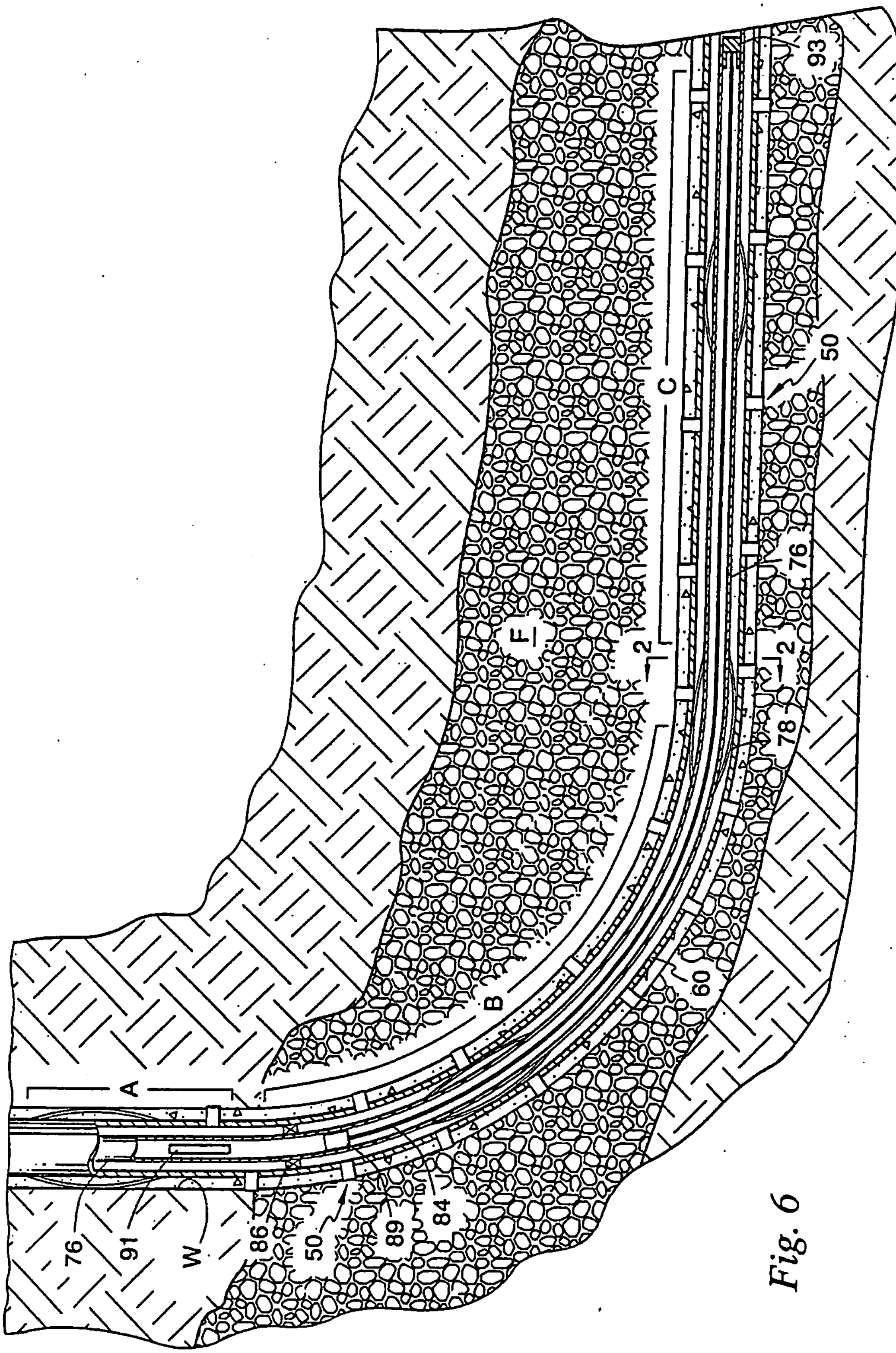

Fig. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/09688

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :E21B 43/112, 43/116
US CL :166/63, 100, 242, 299, 369; 175/4.53
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 166/55.1, 63, 100, 242,297, 299, 369; 175/4.53, 2

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 3,468,386 (Johnson) 23 September 1969, see Figure 1, column 2, lines 10-23 and column 3, lines 6-33.	1-3,5-7,10, 11,14,17,19-21,25-29
Y	US, A, 4,541,486 (Wetzel et al) 17 September 1985, see column 7, lines 25-40.	1-3,5-7,10, 11,14,17,19-21,25-29
Y	US, A, 4,616,701 (Stout et al) 14 October 1986, see column 3, line 56 through column 4, line 12.	1 - 3 , 5 - 7,10,11,14,17, 1 9-21,25-29
A	US, A, 3,326,291 (Zandmer) 20 June 1967, see the entire patent.	1-29

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be part of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
09 December 1993	30 DEC 1993

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